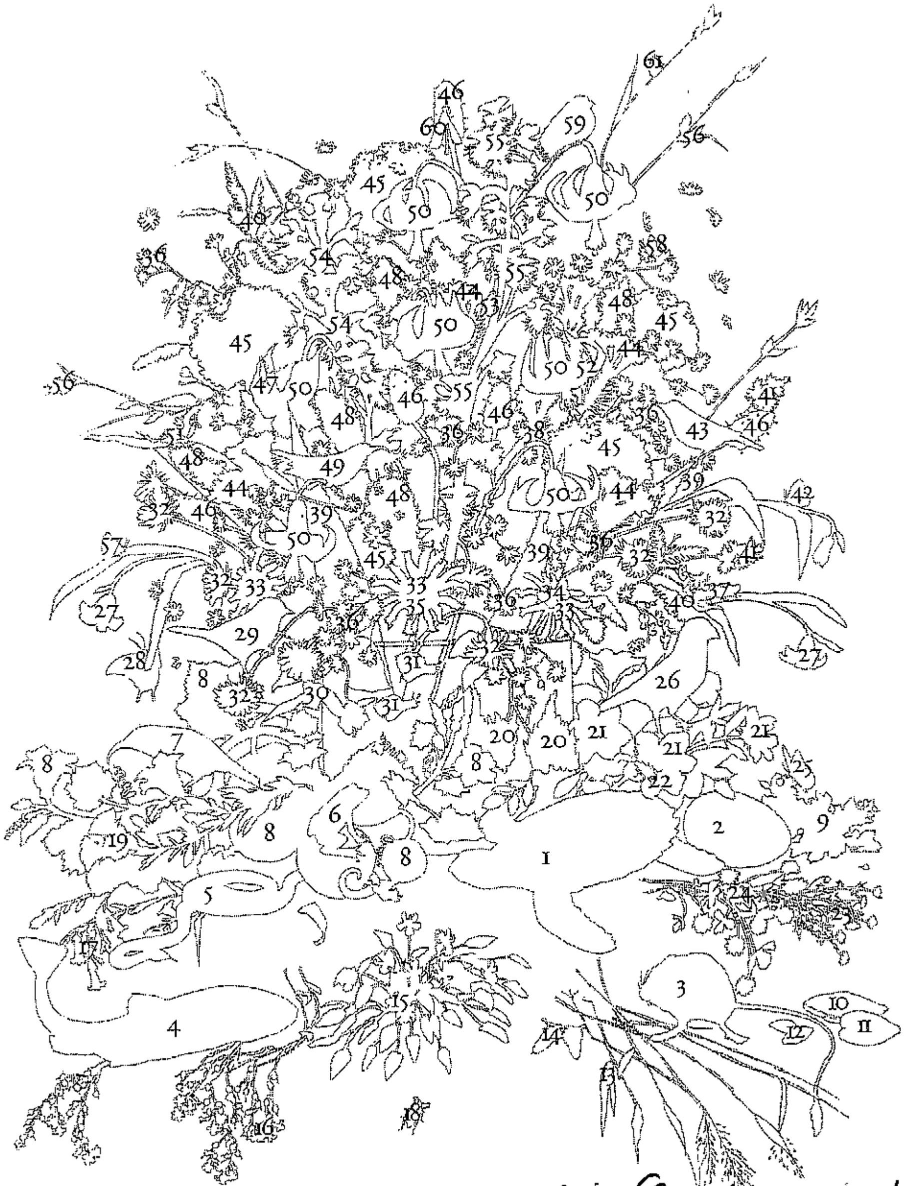
Name: ______________________________

Biodiversity and Bees Reading Packet

Please read and annotate the packet. Good students make lots of notes in the margins! When you are finished with both articles, please write a Prepare for Discussion Paper to share with your peers.

Here are some questions to help guide you in your thinking:

1. What is biodiversity?
2. Why is biodiversity important?
3. How do humans impact biodiversity?
4. What is the problem with bees?
5. Why should I care about bees?



Wilson, E.O. The Future of Life. New York:
Random House, 2002.

ENDANGERED AND EXTINCT SPECIES AND RACES

(represented in jacket art, and as numbered in adjacent diagram)

1. Hawksbill sea turtle—*Eretmochelys imbricata*
2. Condor egg—*Gymnogyps californianus*
3. Giant kangaroo rat—*Dipodomys ingens*
4. Little Kern golden trout—*Oncorhynchus aquabonita whitei*
5. San Francisco garter snake—*Thamnophis sirtalis tetrataenia*
6. Golden toad—*Bufo periglenes*
7. I'iwi—*Vestiaria coccinea*
8. Okeechobee gourd—*Cucurbita okeechobeensis*
9. Presidio manzanita—*Arctostaphylos pungens* var. *ravenii*
10. James spineymussel—*Pleurobema collina*
11. Fat pocketbook pearly mussel—*Potamilus capax*
12. Dwarf wedge mussel—*Alasmidonta heterodon*
13. Geyser's panicum—*Dichanthelium lanuginosum* var. *thermale*
14. Valley oak—*Quercus lobata*
15. Guadalupe violet—*Viola guadalupensis*
16. Missouri bladderpod—*Lesquerella filiformis*
17. Indian Knob mountainbalm—*Eriodictyon altissimum*
18. American burying beetle—*Nicrophorus americanus*
19. Vine Hill clarkia—*Clarkia imbricata*
20. Price's potato bean—*Apios priceana*
21. Na'u—*Gardenia brighamii*
22. Valley elderberry longhorn beetle—*Desmocerus californicus dimorphus*
23. Baker's blennosperm—*Blennosperma bakeri*

24. Running buffalo clover—*Trifolium stoloniferum*
25. Myrtle silver spot—*Speyeria zerene myrtleae*
26. Laysan finch—*Telespiza cantans*
27. Striped adobe lily—*Fritillaria striata*
28. Schaus' swallowtail—*Heraclides aristodemus ponceanus*
29. Golden-cheeked warbler—*Dendroica chrysoparia*
30. McFarlane's four o'clock—*Mirabilis macfarlanei*
31. Oahu tree snails—*Achatinella* spp.
32. Ash meadows sunray—*Enciliopsis nudicaulis* var. *corrugata*
33. Tennessee purple coneflower—*Echinacea tennesseensis*
34. Lotis blue—*Lycaeides argyrognomon lotis*
35. Hungerford's crawling water beetle—*Brychius hungerfordi*
36. Schweinitz's sunflower—*Helianthus schweinitzeii*
37. Shasta salamander—*Hydromantes shastae*
38. Desert slender salamander—*Batrachoseps aridus*
39. Arizona agave—*Agave arizonica*
40. Sensitive joint vetch—*Aeschynomene virginica*
41. San Clemente Island woodland-star—*Lithophragma maxima*
42. Strohbeen's parnassian—*Parnassius clodius strohbeeni*
43. Black-capped vireo—*Viero atricapillus*
44. Santa Ana woollystar—*Eriastrum densifolium* ssp. *sanctorum*
45. Large-fruited sand verbena—*Abronia macrocarpa*
46. Swamp pink—*Helonias bullata*
47. Oblivious tiger beetle—*Cicindela latesignata obliviosa*
48. Contra Costa wallflower—*Erysimum capitatum* var. *angustatum*
49. Nuku pu'u—*Hemignathus lucidus*
50. Western lily—*Lilium occidentale*
51. Antioch Dunes shieldbacked katydid—*Nebuda extincta*
52. Delta green ground beetle—*Elaphrus viridus*
53. Dehli sands flower-loving fly—*Rhaphiomidas terminatus abdominalis*
54. Western fringed prairie orchid—*Platanthera praeclara*
55. Eastern fringed prairie orchid—*Platanthera leucophaea*
56. White sedge—*Carex albida*
57. El Segundo blue—*Euphilotes battoides allyni*
58. Mission blue—*Icaricia icarioides missionensis*
59. 'Akēpa—*Loxops coccineus*
60. San Francisco fork-tailed damsel fly—*Ischnura gemina*
61. San Bruno elfin—*Incisalia mossii bayensis*

In the end, our society will be defined
not only by what we create, but by what
we refuse to destroy.

—John C. Sawhill (1936–2000), president,
The Nature Conservancy, 1990–2000

Essay

Biodiversity: Wildlife in Trouble

Edward O. Wilson
Research Professor, Pellegrino University and Honorary Curator in Entomology, Harvard University

Around the world, biodiversity—defined as the full variety of life from genes to species to ecosystems—is in trouble. Not a week goes by without reports of the imminent end of one species or another. For every celebrity animal that vanishes, biologists can point to thousands of species of plants and smaller animals either recently extinct or on the brink.

There is not one country, not one biome, that remains untouched. Plants and animals—or the mountains, the desert, and the oceans—are affected. The rarest bird in the world, the Spix's macaw, is down to one or possibly two individuals in the palm and river-edge forests of central Brazil. The rarest plant is Cooke's kokio of Hawaii, a small tree with orange-red flowers that once lived on the dry volcanic slopes of Molokai. Today it exists only as a few half plants—branches grafted onto the stocks of other related plants. Despite the best efforts of scientists to save the plant, no branches planted in soil have sprouted roots.

It is difficult to estimate overall rates of extinction. However, biologists generally agree that on the land, at least, and on a worldwide basis, species are vanishing one hundred times faster than before the arrival of humans. The world's flora and fauna are paying the price of humanity's population growth.

Biodiversity is in serious trouble. Responding to the problem, conservation experts have shifted their focus in the past 20 years from individual plant and animal groups (species) to entire threatened habitats, whose destruction would cause the extinction of many species. Such "hot spots" have become the focus of conservation efforts. The logic of the experts is simple: By concentrating conservation efforts on such areas, we can save the largest amount of biodiversity at the lowest economic cost.

The outright elimination of habitats is the leading cause of extinction. But the introduction of exotic species and the diseases they carry follows close behind in destructiveness, along with overhunting or overharvesting of plants and animals. All these factors work together in a complex manner. When asked which ones caused the extinction of any particular species, biologists are likely to give the *Murder on the Orient Express* answer: They all did it. A common sequence in tropical countries starts with the building of roads into wilderness. Land-seeking settlers pour in, clear the rain forest on both sides of the road, pollute the streams, introduce alien plants and animals, and hunt wildlife for extra food. Many native species become rare, and some disappear entirely.

People commonly respond to the evidence of species extinction by entering three stages of denial. The first is, simply: Why worry? Extinction is natural. Species have been dying out for billions of years without permanent damage. Evolution has always replaced extinct species with new ones.

Wilson, E.O. 'Biodiversity: Wildlife in Trouble.' Scientists on Biodiversity. Ed. Linda Koebner et. al. New York: American Museum of Natural History, 1998.

These statements are true—but with a terrible twist. After each of the four greatest environmental disruptions that occurred during the past 400 million years, evolution needed about ten million years to restore Earth's biodiversity. Worse, evolution will be even slower if natural environments have been crowded out by artificial ones. Faced with such a long waiting time, aware that we have inflicted so much damage in a single lifetime, our descendants are going to be—how best to say it?—peeved with us.

Entering the second stage of denial, people ask: Why do we need so many species anyway? Why care, especially since the vast majority are bugs, weeds, and fungi?

It is easy to dismiss the creepy crawlies of the world. However, the value of the little things in the natural world has become extremely clear. Recent experimental studies on whole ecosystems support what ecologists have long suspected: The more species living in an ecosystem, the higher its productivity and the greater its ability to withstand drought and other kinds of environmental strain. Since we depend on working ecosystems to cleanse our water, enrich our soil, and create the very air we breathe, biodiversity is clearly not something to discard carelessly.

Besides creating a livable environment, wild species are the source of products that help support our lives. More than 40 percent of all prescription medicines used by Americans are substances originally extracted from plants, animals, fungi, and microorganisms. Aspirin, for example, the most widely used medicine in the world, was originally derived from a plant *Filpendula ulmaria*, meadowsweet.

Every species on Earth is a masterpiece of evolution, offering a vast source of useful scientific knowledge because it is so thoroughly adapted to the environment in which it lives.

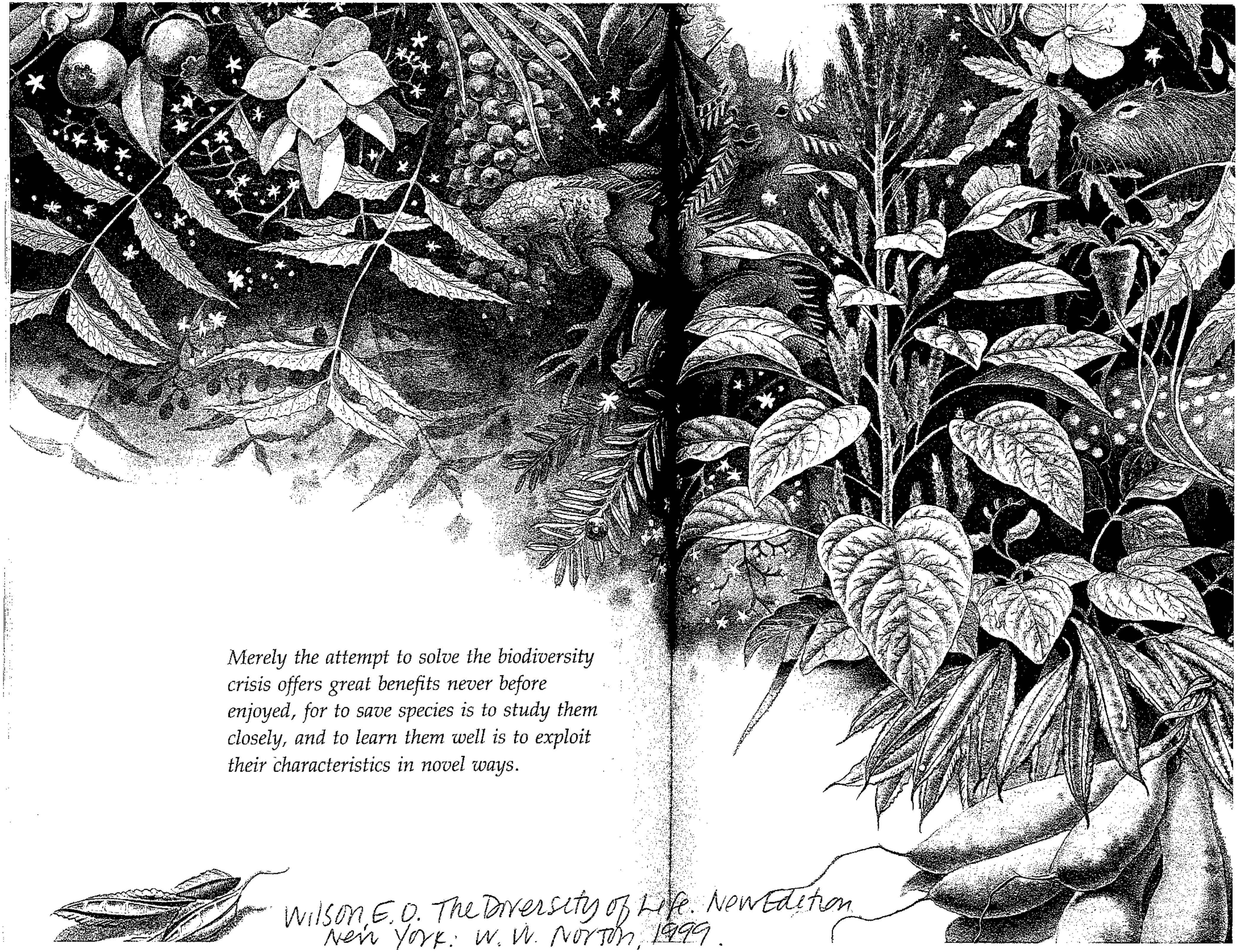
Even when that much is granted, the third stage of denial usually emerges: Why rush to save all the species right now? We have more important things to do. Why not keep live specimens in zoos and botanical gardens and return them to the wild later?

The grim truth is that all the zoos in the world today can hold a maximum of only 2,000 species of mammals, birds, reptiles, and amphibians, out of about 24,000 known to exist. The world's botanical gardens would be even more overwhelmed by the quarter million plant species. To add to the difficulty, no one has come up with a plan to save all the insects, fungi, and other ecologically vital small organisms. And even when scientists are finally ready to return species to independence, the ecosystems in which many live will no longer exist.

The conclusion of scientists and conservationists is practically unanimous: The only way to save wild species is to maintain them in their natural habitats. Considering how rapidly such habitats are shrinking, even that straightforward solution will be an overwhelming task.

In spite of all these difficulties, there is reason for some optimism. With appropriate measures and the will to use them, the destruction can be slowed, perhaps eventually halted, and most of the surviving species saved. Some of the most important steps that can be taken are outlined in the Convention on Biological Diversity signed by 156 nations and the European Union at the 1992 Earth Summit in Rio de Janeiro. The convention was the turning point in the awareness of biodiversity as a world issue. Besides speeding up conservation efforts, the convention awakened many tropical countries, where biological diversity is both the richest and the most threatened.

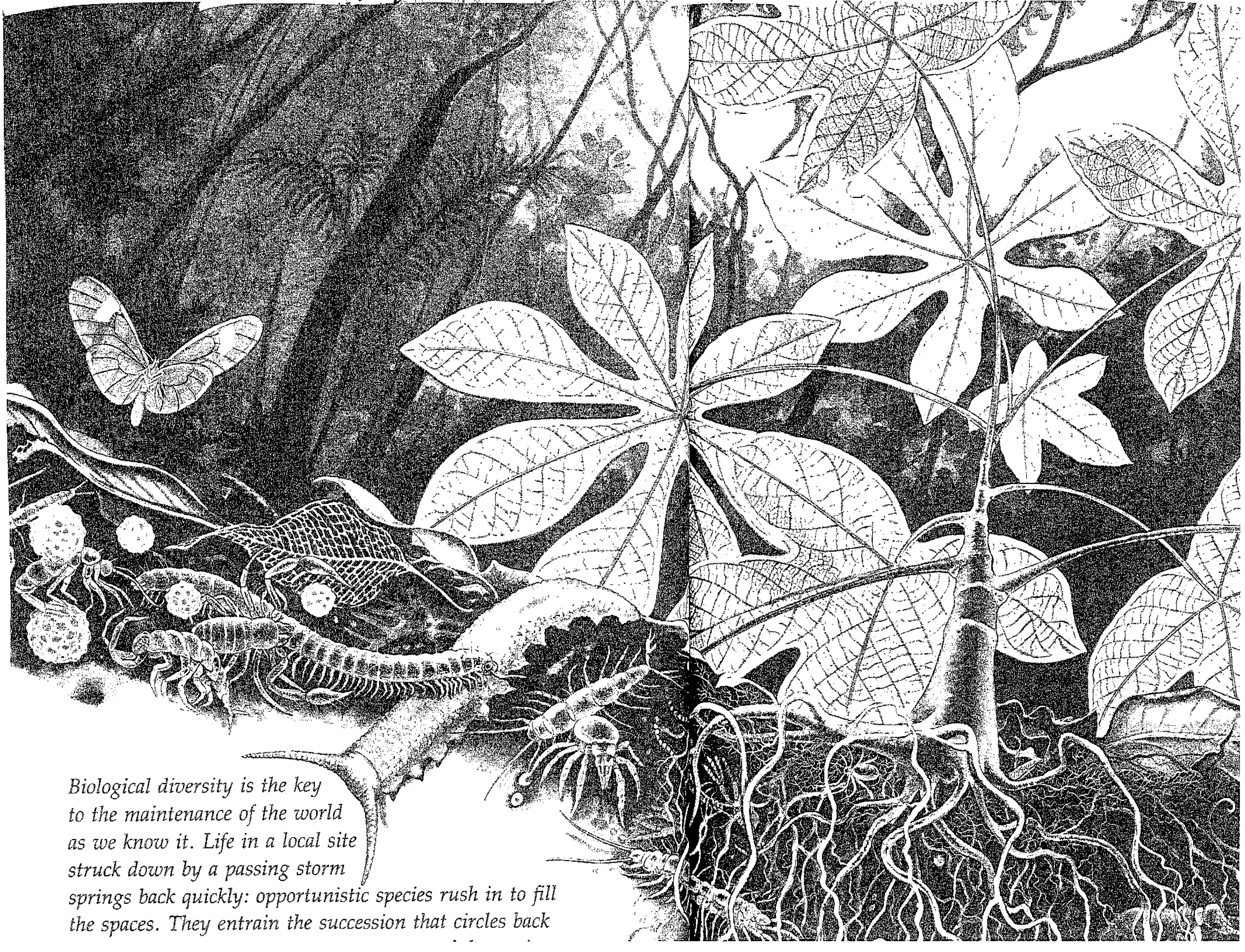
The new approach to biodiversity preservation, uniting conservation and economic development, is not perfect, and it is not yet fully practiced in any country. But it is a promising start. Some of the test projects have succeeded dramatically. They offer a way out of what will otherwise be a biologically barren future. With the world population at six billion and sure to keep on growing rapidly, humanity has entered a dangerous environmental bottleneck. We hope—surely we must believe—that our species will come out the other side in better condition than when we entered. We should make it a goal to take as much of the rest of life with us as is humanly possible.



Merely the attempt to solve the biodiversity crisis offers great benefits never before enjoyed, for to save species is to study them closely, and to learn them well is to exploit their characteristics in novel ways.

Wilson, E.O. The Diversity of Life. New Edition
New York: W. W. Norton, 1999.

Wilson, E.O. The Diversity of Life, New Edition. New York: W.W. Norton, 1999



Biological diversity is the key
to the maintenance of the world
as we know it. Life in a local site
struck down by a passing storm
springs back quickly: opportunistic species rush in to fill
the spaces. They entrain the succession that circles back

We live in a hotspot!

The 25 Biodiversity Hotspots

1. Tropical Andes
2. Mesoamerica
3. Caribbean
4. Atlantic Forest Region
5. Chocó-Darién-Western Ecuador
6. Brazilian Cerrado
7. Central Chile
8. California Floristic Province
9. Madagascar and Indian Ocean Islands
10. Eastern Arc Mts. & Coastal Forests
11. Guinean Forests of West Africa
12. Cape Floristic Province
13. Succulent Karoo
14. Mediterranean Basin
15. Caucasus
16. Sundaland
17. Wallacea
18. Philippines
19. Indo-Burma
20. Mountains of South-Central China
21. Western Ghats and Sri Lanka
22. Southwest Australia
23. New Caledonia
24. New Zealand
25. Polynesia/Micronesia

Source: Cincotta, 2000 (275)

http://www.epa.gov/pesticides/about/intheworks/honeybee.htm
Last updated on Tuesday, May 10, 2011

About Pesticides

You are here: EPA Home Pesticides About Pesticides Pesticide issues in the works
Honeybee colony collapse disorder

Pesticide issues in the works: Honeybee colony collapse disorder

Current as of February 18, 2011

Discovering a problem

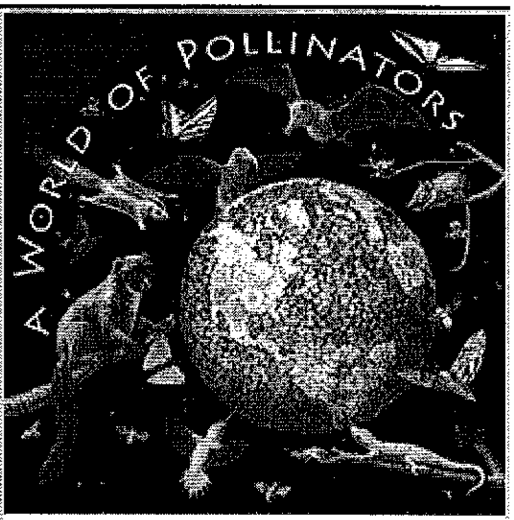
During the winter of 2006-2007, some beekeepers began to report unusually high losses of 30-90 percent of their hives. As many as 50 percent of all affected colonies demonstrated symptoms inconsistent with any known causes of honeybee death: sudden loss of a colony's worker bee population with very few dead bees found near the colony. The queen and brood (young) remained, and the colonies had relatively abundant honey and pollen reserves. But hives cannot sustain themselves without worker bees and would eventually die. This combination of events resulting in the loss of a bee colony has been called Colony Collapse Disorder (CCD).

Though agricultural records from more than a century ago note occasional bee "disappearances" and "dwindling" colonies in some years, it is uncertain whether the colonies had the same combination of factors associated with CCD. What we do know from the most recent data from beekeepers for 2009 is that that CCD appears to still be with us.

Dead bees don't necessarily mean CCD

Certain pesticides are harmful to bees. That's why we require instructions for protecting bees on the labels of pesticides that are known to be particularly harmful to bees. This is one of many reasons why everyone must read and follow pesticide label instructions. When most or all of the bees in a hive are killed by overexposure to a pesticide, we call that a beekill incident resulting from acute pesticide poisoning. But acute pesticide poisoning of a hive is very different from CCD and is almost always avoidable.

There have been several incidents of acute poisoning of honeybees covered in the popular media in recent years, but sometimes these incidents are mistakenly associated with CCD. A common element of acute pesticide poisoning of bees is, literally, a pile of dead bees outside



The 2010 *World of Pollinators* posters are all gone. 2011 posters are coming soon!

Other issues in the works:

- Nanotechnology, the science of small
- Pesticide volatilization

Other Resources

- Pollinator Protection

Questions on Pesticides?

- National Pesticide Information Center (NPIC) 1-800-858-7378 EXIT Disclaimer

Status of Clothianidin Bee Studies

- Clothianidin – Registration Status and Related Information
- Clothianidin Letter (PDF) (6 pp, 529 k, about PDF)
- EPA Response to Clothianidin Letter (PDF) (4 pp, 1 MB, about PDF)

the hive entrance. With CCD, there are very few if any dead bees near the hive. Piles of dead bees are an indication that the incident is not colony collapse disorder. Indeed, heavily diseased colonies can also exhibit large numbers of dead bees near the hive.

Why it's happening

There have been many theories about the cause of CCD, but the researchers who are leading the effort to find out why are now focused on these factors:

- increased losses due to the invasive varroa mite (a pest of honeybees);
- new or emerging diseases such as Israeli Acute Paralysis virus and the gut parasite Nosema;
- pesticide poisoning through exposure to pesticides applied to crops or for in-hive insect or mite control;
- bee management stress;
- foraging habitat modification
- inadequate forage/poor nutrition and
- potential immune-suppressing stress on bees caused by one or a combination of factors identified above.

Additional factors may include poor nutrition, drought, and migratory stress brought about by the increased need to move bee colonies long distances to provide pollination services.

What is being done

The U.S. Department of Agriculture (USDA) is leading the federal government response to CCD. In 2007, USDA established a CCD Steering Committee with representatives from other government agencies, and academia. EPA is an active participant in the CCD Steering Committee. The Steering Committee has developed the Colony Collapse Disorder Action Plan (PDF) (28 pp, 2 MB, about PDF) . The plan has four main components:

1. Survey/Data Collection to determine the extent of CCD and the current status of honeybee colony production and health;
2. Analysis of Bee Samples to determine the prevalence of various pests and pathogens, bee immunity and stress, and exposure to pesticides;
3. Hypothesis-Driven Research on four candidate factors including new and reemerging pathogens, bee pests, environmental and nutritional stresses, and pesticides; and
4. Mitigative/Preventive Measures to improve bee health and habitat and to counter mortality factors.

What EPA is doing

Our role in the federal response to CCD is to keep abreast of and help advance research investigating pesticide effects on pollinators. To date, we're aware of no data demonstrating that an EPA-registered pesticide used according to the label instructions has caused CCD. While our longstanding regulatory requirements for pesticides are designed to protect beneficial insects such as bees, since 2007 we have been looking at many different ways of possibly improving pollinator protection.

For more information

- Bee Die-Off in Germany Unrelated to CCD
- Find out more about colony collapse disorder from the USDA Agricultural Research Service
- Learn about EPA's Pollinator Protection efforts
- EPA Responds to NRDC's 2008 Freedom of Information Act complaint

Seeley, Thomas. The Honey Bee Democracy.
Princeton, NJ: Princeton University Press.

1

INTRODUCTION

Go to the bee,
thou poet:
consider her ways
and be wise.
—*George Bernard Shaw,* Man and Superman, *1903*

Honeybees are sweetness and light—producers of honey and beeswax—so it is no great wonder that humans have prized these small creatures since ancient times. Even today, when rich sweets and bright lights are commonplace, we humans continue to treasure these hard-working insects, especially the 200 billion or so that live in partnership with commercial beekeepers and perform on our behalf a critical agricultural mission: go forth and pollinate. In North America, the managed honeybees are the primary pollinators for some 50 fruit and vegetable crops, which together form the most nutritious portion of our daily diet. But honeybees also provide us another great gift, one that feeds our brains rather than our bellies, for inside each teeming beehive is an exemplar of a community whose members succeed in working together to achieve shared goals. We will see that these little six-legged beauties have something to teach us about building smoothly functioning groups, especially ones capable of exploiting fully the power of democratic decision making.

Our lessons will come from just one species of honeybee, *Apis mellifera*, the best-known insect on the planet. Originally native to western Asia, the Mid-

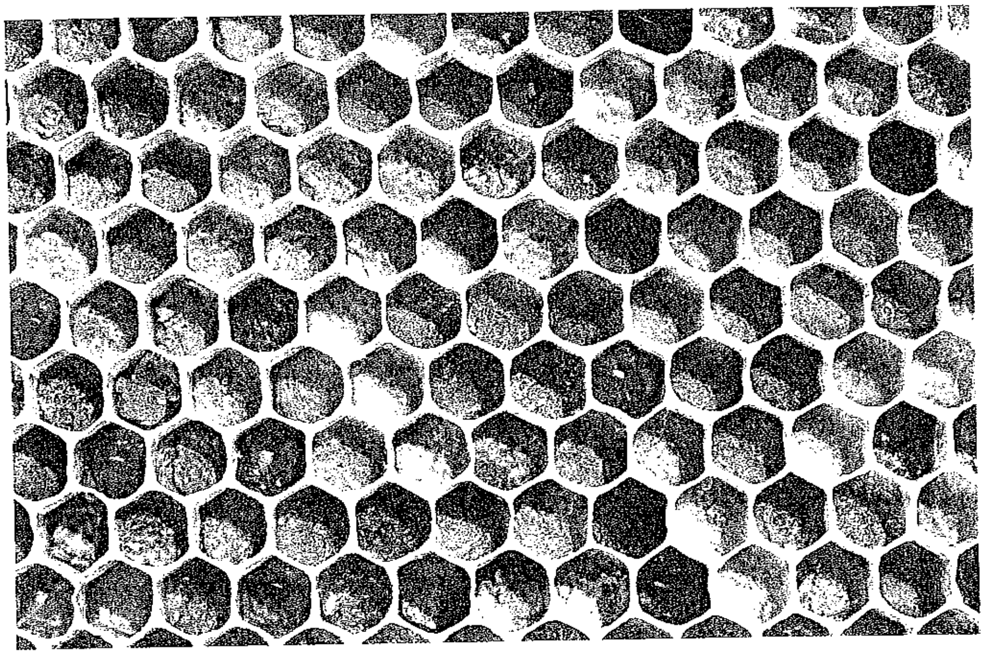


Fig. 1.1 A comb built of beeswax sculpted into hexagonal cells and filled with pollen from various species of plants.

dle East, Africa, and Europe, it is now found in temperate and tropical regions throughout the world thanks to the dispersal efforts of its human admirers. It is a bee that is beautifully social. We can see this beauty in their nests of golden combs, those exquisite arrays of hexagonal cells sculpted of thinnest beeswax (fig. 1.1). We can see it further in their harmonious societies, wherein tens of thousands of worker bees, through enlightened self-interest, cooperate to serve a colony's common good. And in this book, we will see the social beauty of honeybees vividly, and in fine detail, by examining how a colony achieves near-perfect accuracy when it selects its home.

Choosing the right dwelling place is a life-or-death matter for a honeybee colony. If a colony chooses poorly, and so occupies a nest cavity that is too small to hold the honey stores it needs to survive winter, or that provides it with poor protection from cold winds and hungry marauders, then it will die. Given the vital importance of choosing a suitably roomy and snug homesite, it is not surprising that a colony's choice of its living quarters is made not by a few bees acting alone but by several hundred bees acting collectively. This book is about how this sizable search committee almost always makes a good choice. We will uncover the means by which these house-hunting bees scour the neighborhood for potential nest sites, report the news of their discoveries, conduct a frank debate about these options, and ultimately reach an agreement about which site will be their colony's new dwelling place. In short, we will examine the ingenious workings of honeybee democracy.

There is one common misunderstanding about the inner operations of a honeybee colony that I must dispel at the outset, namely that a colony is governed by a benevolent dictator, Her Majesty the Queen. The belief that a colony's coherence derives from an omniscient queen (or king) telling the workers what to do is centuries old, tracing back to Aristotle and persisting until modern times. But it is false. What is true is that a colony's queen lies at the heart of the whole operation, for a honeybee colony is an immense family consisting of the mother queen and her thousands of progeny. It is also true that the many thousands of attentive daughters (the workers) of the mother queen are, ultimately, all striving to promote her survival and reproduction. Nevertheless, a colony's queen is not the Royal Decider. Rather, she is the Royal Ovipositer. Each summer day, she monotonously lays the 1,500 or so eggs needed to maintain her colony's workforce. She is oblivious of her colony's ever-changing labor needs—for example, more comb builders here, fewer pollen foragers there—to which the colony's staff of worker bees steadily adapts itself. The only known dominion exercised by the queen is the suppression of rearing additional queens. She accomplishes this with a glandular secretion, called "queen substance," that workers contacting her pick up on their antennae and distribute to all corners of the hive. In this way, these workers spread the word that their mother queen is alive and well, hence there is no need to rear a new queen. So the mother queen is not the workers' boss. Indeed, there is no all-knowing central planner supervising the thousands and thousands of worker bees in a colony. The work of a hive is instead governed collectively by the workers themselves, each one an alert individual making tours of inspection looking for things to do and acting on her own to serve the community. Living close together, connected by the network of their shared environment and a repertoire of signals for informing one another of urgent labor needs—for example, dances that direct foragers to flowers brimming with sweet nectar—the workers achieve an enviable harmony of labor without supervision.

Collective Intelligence

This book focuses on what I believe is the most wondrous example of how the multitude of bees in a hive, much like the multitude of cells in a body, work together without an overseer to create a functional unit whose abilities far transcend those of its constituents. Specifically, we will examine how a swarm of honeybees achieves a form of collective intelligence in the choice of its home. As will be described in chapter 2, the bees' process of house hunting unfolds in late spring and early summer, when colonies become overcrowded in their nesting cavities (bee hives and tree hollows) and then cast a swarm. When this happens, about a third of the worker bees stay at home and rear a new queen, thereby perpetuating the mother colony, while the other two-thirds of the workforce—a group of some ten thousand—rushes off with the old queen to create a daughter colony. The migrants travel only 30 meters (about 100 feet) or so before coalescing into a beardlike cluster, where they literally hang out together for several hours or a few days (fig. 1.2). Once bivouacked, the swarm will field several hundred house hunters to explore some 70 square kilometers (30 square miles) of the surrounding landscape for potential homesites, locate a dozen or more possibilities, evaluate each one with respect to the multiple criteria that define a bee's dream home, and democratically select a favorite for their new domicile. The bees' collective judgment almost always favors the site that best fulfills their need for sufficiently spacious and highly protective accommodations. Then, shortly after completing their selection process, the swarm bees implement their choice by taking flight en masse and flying straight to their new home, usually a snug cavity in a tree a few miles away.

The enchanting story of house hunting by honeybees presents us with two intriguing mysteries. First, how can a bunch of tiny-brained bees, hanging from a tree branch, make such a complex decision and make it well? The solution to this first mystery will be revealed in chapters 3, 4, 5, and 6. Second, how can a swirl-

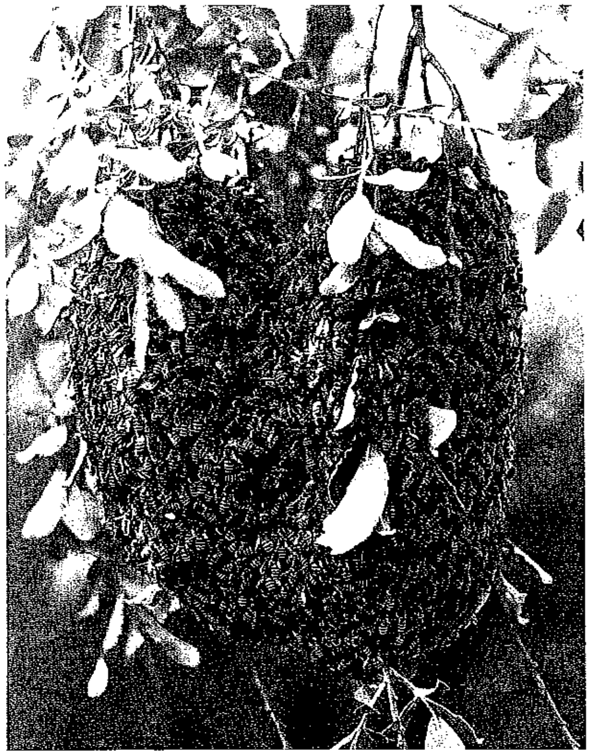


Fig. 1.2 A swarm of honeybees, with approximately ten thousand worker bees and one queen bee.

ing ensemble of ten thousand airborne bees steer themselves and stay together throughout the cross-country flight to their chosen home, a journey whose destination is typically a small knothole in an inconspicuous tree in a remote forest corner? The solution to this second mystery will be revealed in chapters 7 and 8.

We will see that the 1.5 kilograms (3 pounds) of bees in a honeybee swarm, just like the 1.5 kilograms (3 pounds) of neurons in a human brain, achieve their collective wisdom by organizing themselves in such a way that even though each individual has limited information and limited intelligence, the group as a whole makes first-rate collective decisions. This comparison between swarms and brains might seem superficial, but there is real substance here. Over the last two decades, while other sociobiologists and I have been analyzing the behavioral mechanisms of decision making by insect societies, neurobiologists have been investigating the neuronal basis of decision making by primate brains. It turns but there are intriguing similarities in the pictures that have emerged from these two independent lines of study. For example, the studies of individual neuron activity associated with the eye-movement decisions in monkey brains and the studies of individual bee activity associated with nest-site decisions in honeybee swarms have both found that the decision-making process is essentially a competition between alternatives to accumulate support (e.g., neuron firings and bee visits), and the alternative that is chosen is the one whose accumulation of support first surpasses a critical threshold. Consistencies like these suggest that there are general principles of organization for building groups far smarter than the smartest individuals in them. We will explore these principles in chapter 9, where we will compare the decision-making mechanisms of bee swarms and primate brains, and in chapter 10, where we will review the lessons that have been learned from the bees about how to structure a group so that it functions as a smart decision maker.

Group decisions by humans are widespread and important, whether they are small-scale (e.g., agreements made among friends and colleagues), medium-scale (e.g., choices made in democratic town meetings), or large-scale decisions (e.g., national elections or international agreements). Not surprisingly, humans have puzzled over how to optimize group decision making for millennia, at least since Plato's *The Republic* (360 BC) and no doubt long before, and yet many questions remain open about how humans can improve social choice. In chapter 10, I will offer some suggestions, what I call "Swarm Smarts" because they have been learned from the bees, on how human groups can organize themselves to improve their decision making. The American essayist Henry David Thoreau expressed skepticism about the wisdom of crowds when he wrote, "The mass never comes up to the standard of its best member, but on the contrary degrades itself to a level with the lowest." The German philosopher Friedrich Nietzsche was even more negative about group intelligence when he wrote, "Madness is rare in individuals—but in groups . . . it is the rule." Certainly there are many examples of groups making lousy decisions—think of stock market bubbles or of deadly stampedes from burning buildings—but the reality of honeybee swarms making good decisions shows us that there really are ways to endow a group with a high collective IQ.

Dancing Bees

The scientific story told in this book started in Germany almost seventy years ago, in the summer of 1944, when a distinguished professor of zoology at the University of Munich, Karl von Frisch, made a revolutionary discovery for which he would eventually receive the Nobel Prize: an insect, the worker honeybee, can inform her hive mates of the direction and distance to a rich food source by means of dance behavior. Von Frisch had already known for nearly thirty years that when a lone forager finds a rich source of nectar, she returns excitedly to her hive and performs a conspicuous "waggle dance." In performing this eye-catching behavior, the dancer walks straight ahead on the vertical surface of a comb, waggling her body from side to side, then she stops the "waggle run" and turns left or right to make a semicircular "return run" back to her starting point, whereupon she produces another waggle run followed by another return run, and so on (fig. 1.3). Each waggle dance consists, therefore, of a series of dance circuits, and each dance circuit contains a waggle run and a return run. Von Frisch also knew that a bee may continue dancing for some seconds or even some minutes, all the while trailed by unemployed foragers that, in his own words, "take part in each of her manoeuvrings so that the dancer herself, in her madly wheeling movements, appears to carry behind her a perpetual comet's tail of bees." Furthermore, he knew well that after a dance-follower has tripped along behind a dancer throughout several circuits of her dance, she rushes out of the hive to search for the bonanza announced by the dancing bee. But before 1944, von Frisch thought that the only thing the dance-followers learned from the dancer was the fragrance of the flowers she had visited—which they detected by holding their antennae close to the dancer to smell the floral scents adhering to her body—and that upon leaving the hive the newly aroused bees simply searched in ever-expanding circles until they discovered flowers with the memorized fragrance. What von Frisch discovered in 1944 was nearly incredible: the dance-followers did not search for flowers with the matching scent everywhere around the hive, but only in the vicinity of where the dancer had foraged, even if she had foraged in a remote spot, such as along a shady lakeside trail far from the hive. Without a doubt, the newcomers were somehow acquiring from the successful forager information about food-source

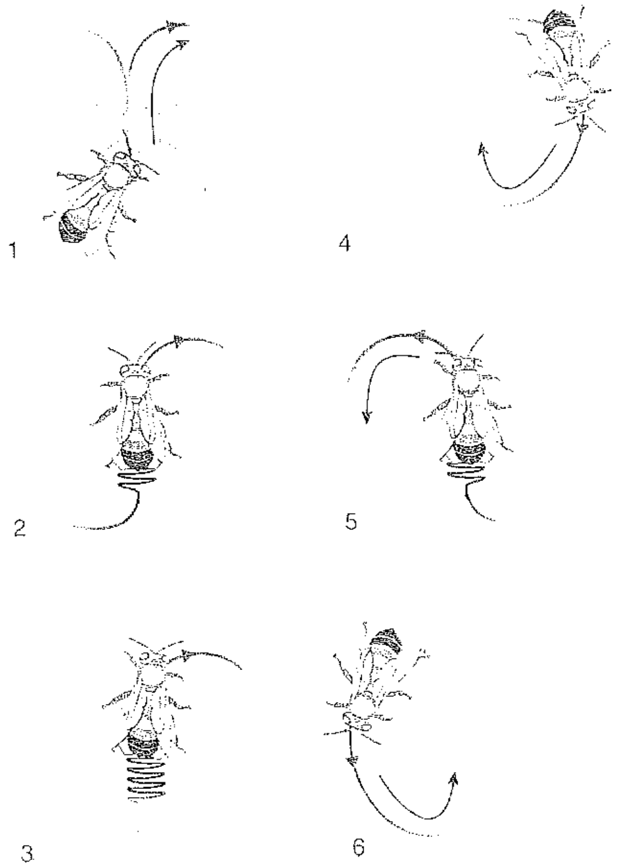


Fig. 1.3 The movement pattern of a worker bee performing a waggle dance on the vertical surface of a comb inside her colony's hive. The bee is shown performing two circuits of the waggle dance.

location as well as food-source scent. Could this location information be communicated inside the hive, by means of the bees' dances?

The answer turned out to be a definitive *yes*. In the summer of 1945, amid the chaos in Europe following the end of World War II, von Frisch returned to his dancing bees, now observing their movements more closely than ever before, examining them for clues that would help him solve his mystery. He discovered that when a bee performs a waggle run inside a dark hive, she produces a miniaturized reenactment of her recent flight outside the hive over sunlit countryside, and in this way indicates the location of the rich food source she has just visited (fig. 1.4). Her encoding of the information about food-source location works as

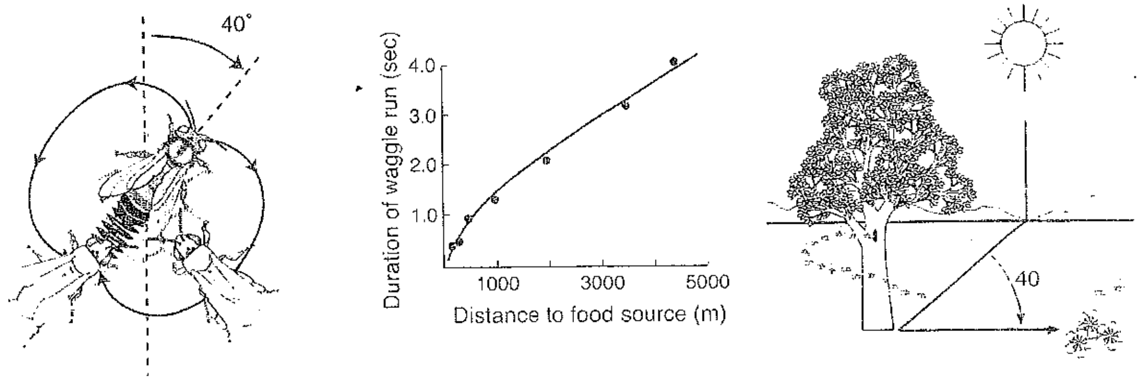


Fig. 1.4 How a dancing bee encodes information about the distance and direction to a rich patch of flowers. Distance coding: The duration of each waggle run is proportional to the length of the outbound flight. Direction coding: Outside the hive the bee notes the angle of her outbound flight relative to the sun's direction, and then inside the hive she orients her waggle runs at the same angle relative to straight up on the comb. Two followers are acquiring the dancing bee's information.

follows. The duration of the waggle run—made conspicuous despite the darkness by the dancer audibly buzzing her wings while waggling her body—is directly proportional to the length of the outward journey. On average, one second of the combined body-waggling/wing-buzzing represents some 1,000 meters (six-tenths of a mile) of flight. And the angle of the waggle run, relative to straight up on the vertical comb, represents the angle of the outward journey relative to the direction of the sun. Thus, for example, if a successful forager walks directly upward while producing a waggle run, she indicates that "the feeding place is in the same direction as the sun." Or, if the waggling bee heads 40 degrees to the right of vertical, her message is, "The feeding place is 40 degrees to the right of the sun," as shown in figure 1.4. Perhaps most remarkably, the bees that follow a dancer, monitoring her waggle runs, are able to decode her dance and put her flight instructions into action.

While von Frisch was deciphering the secret message of the waggle dance, he was also supervising a young graduate student, named Martin Lindauer, who was to prove von Frisch's most gifted disciple in revealing the inner workings of